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Abstract

Major efforts over the past six months included: (i) post-delivery work on the level 2 cloud optical depth (MOD_PR06OD) algorithm; (ii) further analysis of MAS and CAR data from the FIRE III Arctic Cloud Experiment, conducted in Fairbanks and Barrow, Alaska, during May and June 1998; (iii) participation in planning meetings and site surveys for the SAFARI 2000 experiment to be held in Southern Africa, and (iv) continued work on previous experimental data sets.

I.   Task Objectives

With the use of related airborne instrumentation, such as the MODIS Airborne Simulator (MAS) and Cloud Absorption Radiometer (CAR), our primary objective is to extend and expand algorithms for retrieving the optical thickness and effective radius of clouds from radiation measurements to be obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS). The secondary objective is to obtain an enhanced knowledge of surface angular and spectral properties that can be inferred from airborne directional radiance measurements.

II. Work Accomplished

a.   *MODIS Code Delivery and Related Software Development*

MOD06 Level-2 cloud retrieval code

Mark Gray worked on increasing the runtime speed of the MOD_PR06OD package as well as making improvements to emission calculation subroutines, algorithm logic, day/night terminator logic, surface ice detection, and integration of the new ancillary package. A 3-D linear interpolation was written to replace the existing Lagrangian interpolation, resulting in a 50% reduction in code execution time. Eric Moody, a new hire since the last reporting period, has been familiarizing himself with the Level-2 code.

Jason Li delivered the MOD06OD_L2 ancillary data package version 2.2.0 in May. This will be the at-launch code. New features of this code include: (i) the ability to continue executing when an input file is missing (in the worst case scenario, the ancillary package will return a file filled with missing values); (ii) all routines are now written in FORTRAN 90 with dynamic memory allocation resulting in the code being independent of granule size; (3) reading both current and upcoming 1° × 1° resolution DAO products, however at launch the source

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mode is set exclusively to NCEP; and (4) reading the NISE dataset when it becomes available. In addition, Jason Li has completed two more MODIS-related deliveries: Set_Process_Tag and getSnowIceMask_nise.

Final libraries (look-up tables) were successfully generated for MODIS Level 2 processing by Peter Soulen. The final tables for diffusion domain asymptotic parameters were calculated using two independent programs: a program written by Teruyuki Nakajima using algorithms from Nakajima and King (1992) and a program written by Michael King based on algorithms from van de Hulst (1980). The asymptotic parameters calculated using these two different methods agreed extremely well (with some parameters agreeing to within 0.1%).

MOD08 Level-3 atmosphere code

Using modifications to the Monthly Global MOD08 software, the MODIS Level-3 Joint Atmospheres (MOD08) Eight-Day Global Product HDF structure file generation (MOD_PR08WC) and algorithm programs (MOD_PR08W) were completed by Paul Hubanks. A new file specification, process control file (PCF), README, and packing list was created from the monthly product templates and delivered to the MODIS Science Data Support Team (SDST) for integration.

MODIS Level-3 web site development

Paul Hubanks designed and engineered preliminary web sites for both the Cloud Retrieval Group and the MODIS Atmosphere Group.

The Cloud Retrieval Group web site currently has 4 sections: Home, Projects, Publications, and Staff. All publications are available in Portable Document Format (PDF); a link to the free Adobe Acrobat Reader is included. The site is located at http://ltpwww.gsfc.nasa.gov/crg.

The MODIS Atmosphere web site contains a tabular breakdown of the content (Scientific Data Sets) of the MODIS Atmosphere HDF products. A first draft of the MOD04_L2 (aerosol), MOD06_L2 (cloud), MOD35_L2 (cloud mask), and MOD08_D3 (level-3 daily joint atmosphere) product web sites, contained within the structure of the MODIS-Atmosphere site, was completed. Over 90 pages have been implemented thus far. The web site and all product sites can be viewed from: http://ltpwww.gsfc.nasa.gov/MODIS-Atmosphere.

MODIS product visualization

Jason Li developed an EOS-HDF data reader on behalf of the MODIS atmospheric group. He is now working on the display portion of the program that includes IDL software tools to display MODIS N-day test cloud mask results. These efforts will produce a prototype model for use in displaying MODIS atmosphere products.

Paul Hubanks modified and expanded the capabilities of an automated browse creation IDL script to create a complete set of browse images that represent the MODIS Atmosphere Daily Global Joint (MOD08_D3) product. The script was originally written by Bill Ridgway and Jason Li. Modifications included: read/adjust color table, build color bar, read and scale data, add lat-lon lines, create annotations, build master image, and save as GIF file. The modified script was run on the MOD08_D3 HDF product file generated from the MODIS N-Day test data set. Over 1500 images from the 400 scientific data sets contained within this file were produced and ported to the MODIS-Atmosphere web site.

Hubanks also designed and developed a web-based browse system for MOD08_D3 using javascript. The browse system can be viewed at http://ltpwww.gsfc.nasa.gov/MODIS-Atmosphere/MOD08_D3/browse.html.

b. MODIS-related Algorithm Studies

Ice Cloud Retrievals

Drs. Ping Yang and Kuo-Nan Liou completed calculations of a unique library of phase functions for ice crystals of six different habits (hexagonal plates, hollow columns, solid columns, two-dimensional bullet rosettes, and aggregates of hexagonal columns) for 27 different sizes (maximum dimensions ranging from 1-4000 μm) at 10 sub-channel wavelengths in each of seven MODIS cloud remote sensing bands. This extensive library enables the MODIS group to calculate phase functions that are averaged not only over size and habit, but also averaged over spectral response functions for each of the visible and near-infrared bands. In May, during his stay as Visiting Scientist at the Mesoscale and Microscale Meteorology Division of NCAR, Peter Soulen developed software for calculating phase functions averaged over size and MODIS spectral response functions. Using this software and these libraries, preliminary calculations were done to determine the effect of crystal habit on cirrus cloud reflectance in the visible and near-infrared, so that estimates could be made of likely biases in retrieving optical thickness and effective radius (volume/projected area) of cirrus clouds as a result of crystal habit. These results were presented at the 10th AMS Conference on Atmospheric Radiation in Madison, Wisconsin.

In a related effort, Bryan Baum of the NASA Langley Research Center and the Cooperative Institute for Meteorological Satellite Studies (CIMSS) at the University of Wisconsin has been working on the development of two algorithms for potential use in MODIS cloud processing: a cloud thermodynamic phase algorithm using solar (visible/near-IR) bands, and a cloud overlap detection algorithm. These algorithms have been tested using MAS data from the SUCCESS field campaign. Three papers have been submitted for publication.

c. MODIS-related Instrumental Research

CAR characterization

Jason Li devised a method for obtaining measurements of the Cloud Absorption Radiometer (CAR) roll, pitch, and yaw offset angles with respect to the University of Washington CV-580 aircraft's GPS reference frame. In addition, he wrote software to calculate the CAR's pixel viewing zenith and azimuth angles, taking into account the net CAR pitch angles. Jason, together with Tom Arnold, traveled to the University of Washington in Seattle, Washington and NASA Ames Research Center in Moffett Field, California from February 17-26 to obtain the necessary measurements.

A report entitled "Determining CAR Alignment with Respect to the GPS Frame," by Jason Li, concluded that the roll angle alignment of the CAR is in good shape. However, there is a 1.5° roll angle difference for the BRDF and starboard viewing modes, depending on the approaching directions. The CAR instrument pitches down about 2.4° in the BRDF mode.

CAR Data processing

Tom Arnold traced down the origin of the voltage offset problems encountered by the CAR data system. A final version of the processing program was then developed, and all CAR data prior to 1998 were reprocessed. All existing BRDF measurements were reanalyzed using the offset-corrected CAR measurements, and BRDF plots, tables, and figures were generated for each scene. A summary table was made of all available BRDF data. As a result of this effort, Tom Arnold completed the processing of BRDF data over Arctic sea ice and tundra acquired during the ARMCAS (June 1995) and LEADEX (April 1992) experiments. The results are currently being prepared for publication. He has also worked with Peter Soulen on SCAR-A, the Kuwait oil fire, and TARFOX data sets.

Jason Li worked on software to improve the CAR data processing flow, including development of Level-1A (unpacked from Level-0 raw data) and Level-1B (radiometric correction, data quality checks, and improved bad data handling capabilities that are crucial for processing FIRE/ACE data) files. He is also in the process of redesigning the CAR level-1B format that is expected to be completed later this summer, after which he will begin reprocessing all FIRE/ACE data.

d. MODIS-related Field Campaign Efforts

From February 20 to March 12, Si-Chee Tsay participated in the intensive observational period (IOP) of the Electro-Optical Propagation Assessment in Coastal Environments (EOPACE) study, which was conducted in the vicinity of the Army Corps of Engineers research pier at Duck, North Carolina. The purpose of this IOP was to study the transport of coarse marine aerosols, their microphysical properties, and the radiative transfer environment in a coastal zone. Also stud-

ied was the development of the planetary boundary layer as winds moved air parcels offshore from the continent into the Atlantic Ocean. The objective behind this Navy/NASA collaboration was to study the radiative environment in a coastal zone. Coastal zones present special problems in atmospheric optics. Ocean color and sea surface temperature exhibit strong gradients. White capping and sun glint (which are highly wind speed dependent) cause further ocean color changes. A large portion of the light extinction budget is accounted for by large and giant sized aerosol particles that are difficult to characterize. The Navy/NASA collaborators are currently analyzing the radiation data acquired during this experiment. Special emphasis is being placed on reducing the surface flux measurements and hyperspectral radiometer data collected on the CIRPAS twin otter aircraft.

From March 1-12, Si-Chee Tsay participated in another airborne field campaign, this time along with limited surface remote sensing measurements, in Bethlehem, South Africa. The purpose of this experiment was to measure the spectral and seasonal characteristics of fire and smoke plumes, clouds, vegetation, crops, and forest. Data processing is currently underway. Figure 1 shows a photograph of the aircraft base and runway (right), with an image of the same area obtained at 0.68 µm (left). Calibration tarps, having a reflectance of 4%, 8%, 48%, and 64% reflectance, are clearly seen at the center of the image (and on the right hand side of the runway in the photograph). A follow-up dry season (August - September

Figure 1. Photograph of aircraft, base, and runway (right) in Bethlehem, South Africa with an image of the same area at wavelength 0.68 µm (left). The tarps at 4%, 8%, 48%, and 64% reflectance, used for cross-calibration, are clearly seen at the center of the image.

1999) campaign will be conducted at Skukuza, Kruger National Park, South Africa, to complete a one-year research cycle. At this time, a suite of surface remote sensing instruments, including passive flux radiometers, a micropulse lidar, and a newly developed microwave radiometer, will be deployed to study the atmosphere-surface energetics and to intercompare atmospheric retrievals from airborne, spaceborne and ground-based remote sensing.

Several members of the group (King, Tsay, Platnick) took part in planning meetings and site surveys for the Southern Africa Regional Science Initiative year 2000 experiment (SAFARI 2000). This experiment, to be conducted during several periods in southern Africa, including both wet and dry seasons, will study biomass burning, industrial pollution, land surface-atmosphere processes, cloud and precipitation processes, and their effects on the southern Africa ecosystem. An intensive observational period will be conducted during the dry season (August and September 2000) and include remote sensing observations from the Terra spacecraft and the NASA ER-2 (with airborne versions of MOPITT, MISR, and MODIS, as well as other instruments). The remote sensing retrievals will be validated against in situ meteorological, aerosol, and cloud data from the University of Washington CV-580 aircraft and two South Africa Weather Bureau Aerocommander 690A aircraft, as well as numerous instrumented ground sites. This initiative is being built around a number of on-going, already funded activities by NASA, the international community, and southern African countries.

e.   MODIS-related Services

Meetings

1. Michael King and Steven Platnick attended the *ALPS'99 Conference on Ocean Color, Land Surfaces, Radiation and Clouds, and Aerosols*, Méribel, France, 18-22 January 1999.

2. Michael King, Si-Chee Tsay, and Steven Platnick attended the *FIRE-ACE/SHEBA Meeting*, Tucson, AZ, 25-29 January 1999.

3. *MODIS Science Team meeting* and *Atmosphere Discipline Group Meeting*, Greenbelt, MD, 4-6 May 1999. Attended by M. Gray, P Hubanks, M. D. King, S. Platnick, P. Soulen, J. Li, E. Moody, and S. C. Tsay.

4. Michael King, Steven Platnick, and Si-Chee Tsay attended the *SAFARI 2000 Workshop*, Boulder, CO, 12-14 May 1999.

5. Michael King regularly attended weekly MODIS Technical Team meetings.

6. Michael King attended *Science Executive Committee* meetings in Chicago (25 February), Goddard (3 May), and Vail (15 June).

7. Michael King organized, chaired, and attended the *EOS Investigators Working Group* meeting, Vail, Colorado, 15-17 June 1999.

Presentations

1. King, M. D., Y. J. Kaufman, D. Tanré and T. Nakajima, "Remote sensing of tropospheric aerosols from space: Past, present, and future," presented at the *ALPS'99 Conference on Ocean Color, Land Surfaces, Radiation and Clouds, and Aerosols,* Méribel, France, 18-22 January 1999 (invited).

2. Platnick, S., J. Li, M. D. King, S. C. Tsay, G. T. Arnold, M. Gray, P. V. Hobbs and A. Rangno, "Cloud bidirectional reflectance measurements of arctic stratus during FIRE-ACE," presented at the *ALPS'99 Conference on Ocean Color, Land Surfaces, Radiation and Clouds, and Aerosols,* Méribel, France, 18-22 January 1999.

3. Dubovik, O., B. N. Holben, M. D. King, A. Smirnov, T. F. Eck, S. Kinne and I. Slutsker, "A flexible inversion algorithm for retrieval of aerosol optical properties from sun and sky-radiance measurements," presented at the *ALPS'99 Conference on Ocean Color, Land Surfaces, Radiation and Clouds, and Aerosols,* Méribel, France, 18-22 January 1999.

4. King, M. D., "Remote sensing of clouds, sea ice, and leads from the ER-2," presented at the *FIRE-ACE Science Team Meeting,* Tucson AZ, 25-29 January 1999 (invited).

5. Platnick. S., M. D. King, S. C. Tsay, G. T. Arnold, H. Gerber, P. V. Hobbs, and A. Rangno, "Optical thickness and effective radius retrievals of liquid water clouds over ice and snow surfaces," presented at the *FIRE-ACE Science Team Meeting,* Tucson AZ, 25-29 January 1999.

6. Tsay, S. C., "Airborne measurements of surface anisotropy in the arctic," presented at the *FIRE-ACE Science Team Meeting,* Tucson AZ, 25-29 January 1999.

7. King, M. D., and C. Scolese, "The Earth Observing System: Status of the first series & early science investigations," presented at the *37th Goddard Memorial Symposium,* American Astronautical Society, Greenbelt, Maryland, 17 March 1999 (invited).

8. Tsay, S. C., "Radiation measurements during the Aerosol Recirculation and Rainfall Experiment (ARREX/SAFARI-2000)," presented at the *NASA EOS SAFARI-2000 Workshop,* Boulder, CO, 12-14 May 1999.

9. Gatebe, C. K., "Aerosol transport over equatorial Africa," presented at the *American Geophysical Union Spring Meeting,* Boston, MA, 1–4 June 1999.

Seminars

1. Platnick, S., "Cloud retrievals in the solar spectrum," presented in the Cloud and Radiation Branch, NASA Goddard Space Flight Center, Greenbelt, MD, 24 February 1999.

2. Platnick, S., "A review of cloud remote sensing in the solar spectrum," presented at the Department of Atmospheric and Oceanic Sciences, University of Wisconsin, Madison, WI, 15 March 1999.

III. Data/Analysis/Interpretation

a. FIRE-ACE

<u>MAS FIRE-ACE cloud retrievals</u>

Several MAS flights obtained during FIRE-ACE have been used to develop modified cloud retrieval algorithms for clouds overlying snow and ice surfaces. The algorithms use only SWIR and MWIR bands (1.6, 2.1, and 3.7 μm) for which the surface reflectance of snow/ice is relatively small. Further algorithm analysis and visualization work by Steven Platnick and Jason Li has been made on the MAS FIRE-ACE data set.

In particular, an especially problematic scene from 6 June 1998 was analyzed. In this scene, a variety of surface reflectances (in the visible and near-infrared bands that are typically part of cloud retrieval algorithms) were found in the vicinity of Barrow, Alaska, due to the presence of open water, sea ice, frozen ponds, and wet tundra. Figure 2a shows a mapped clear sky visible MAS image of the region around Barrow on 2 June 1998. Figure 2b shows the same region on 6 June when a boundary layer stratus deck was present. The effect of the underlying surface on the overall scene reflectance is clearly discernable across the land-ocean boundary. Figure 3 shows the optical thickness and effective radius retrievals for the 6 June cloud using this new algorithm. Underlying surface discontinuities are not noticeable in the retrievals across the land-ocean boundary, as expected if the cloud is relatively homogeneous in this area. The thinner cloud thickness in the region to the northeast is apparently real and not an artifact of the surface. Optical thickness, effective radius, and liquid water path retrievals in the vicinity of Barrow are all in good agreement with in situ instruments flown on the University of Washington CV-580. This work was reported at the 10th AMS Conference on Atmospheric Radiation.

b. CAR Analysis

<u>CAR BRDF Measurements</u>

During the last half-year, additional surface bidirectional reflectance measurements obtained with the Cloud Absorption Radiometer (CAR) during previous

MAS band 3 (0.67 μm)
6 June 98

wet tundra from 2 June MAS obs.
$R_{0.67} = 0.30 \pm 0.14$
$R_{1.6} = 0.06 \pm 0.04$
$R_{2.1} = 0.04 \pm 0.03$

photo A
x sea ice*

open water*

sea ice*

open water

photo B
x

NSA ARM site

frozen ponds

Latitude
Longitude

* from CAR observations

MAS band 3 (0.67 μm)
2 June 98

Pt. Barrow
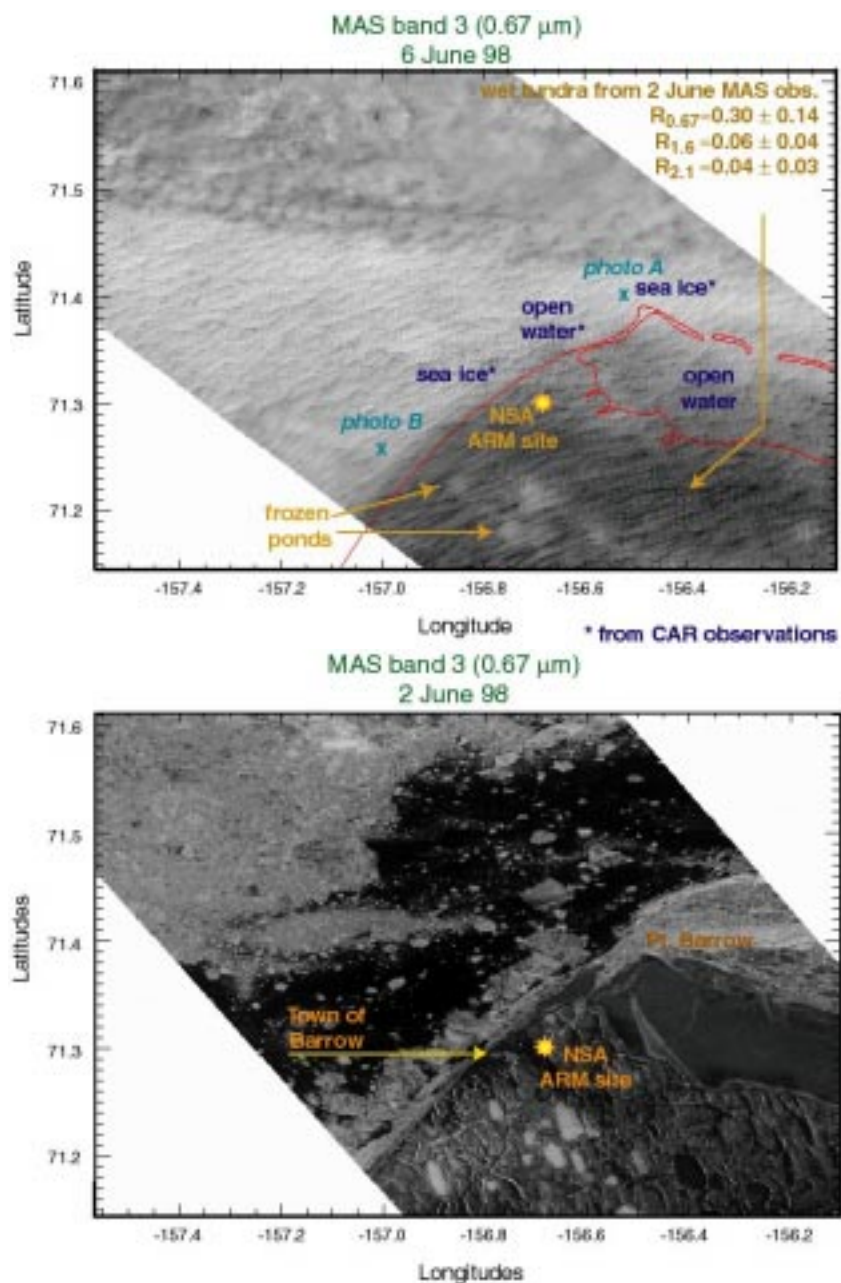
Town of Barrow

NSA ARM site

Latitudes
Longitudes

Figure 2. MAS band 3 (0.67 μm) images obtained on two days in the vicinity of Barrow, AK during (a) clear sky, 2 June 1998, and (b) cloudy conditions, 6 June.

field campaigns were processed and analyzed. Among the surfaces analyzed were: haze layer over the Great Dismal Swamp, Virginia, desert dust, Persian Gulf water, sunglint off the Atlantic Ocean, Arctic tundra, sea ice, and snow over sea ice. Papers on these results have been prepared for publication by Soulen et al. and Arnold et al.

Charles Gatebe has been studying the surface BRDF pattern in the MODIS 2.1 μm band relative to the 0.47 and 0.68 μm bands, for use in remote sensing of aerosols over land. This study uses CAR data collected over Brazil during the Smoke,
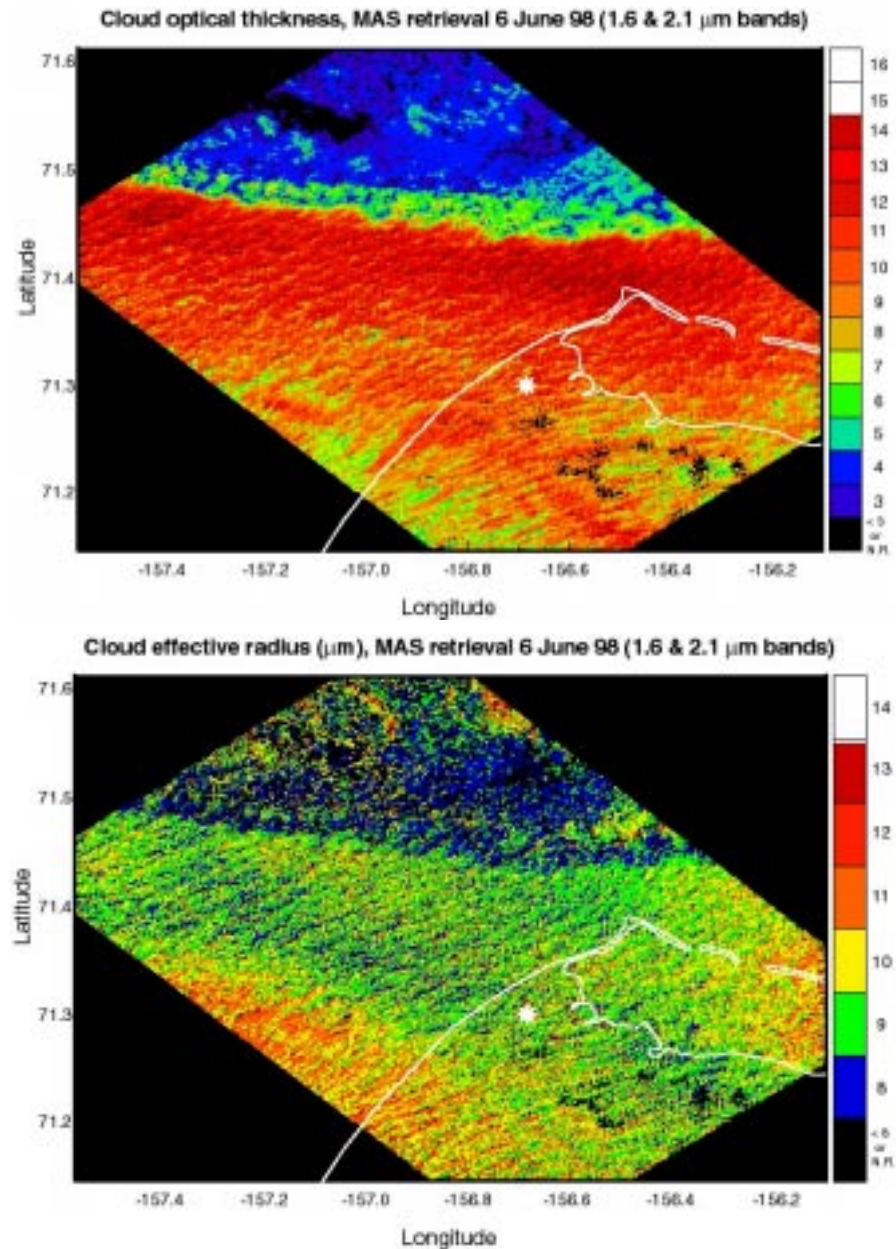
Figure 3. Cloud retrievals of (a) optical thickness, and (b) effective radius, for the 6 June 1998 boundary layer stratus cloud of Fig. 2b near Barrow, AK. The cloud deck was about 300 m thick with cloud tops at 900 m.

Clouds and Radiation-Brazil (SCAR-B) experiment for the period 17 August-20 September 1995. The BRDF analysis emphasizes results for off-nadir view angles compared with nadir views. Preliminary results indicate the ratios of the CAR blue channel (0.472 µm) to the 2.2 µm channel vary between 0.286 at nadir to 0.300 at 40° off-nadir, and then drop down to 0.171 at 55° and 0.091 at 85° off-nadir. With the CAR red channel (0.675 µm), the ratio varies between 0.691 at nadir and 0.860 at 40° off-nadir, and then decrease from 0.542 at 55° to 0.335 at 85°. These results clearly indicate the limit and constraints of the ratio technique to non-nadir view angles.

IV. Anticipated Future Actions

1. Continue testing to improve the computational efficiency of the MODIS *v2* cloud retrieval algorithm.

2. Continue to analyze, test, and refine the delivered MODIS level-2 and level-3 algorithms.

3. Continue analysis of FIRE-ACE and other existing data sets.

4. Continue studying the implication of measured CAR spectral BRDF data on the MODIS aerosol retrieval algorithm over land.

V. Problems/Corrective Actions

The main MODIS emphasis during the next reporting period is to improve the computational efficiency of the MOD06 cloud retrieval code to enable large scale processing of MODIS data in December. In addition, the radiative transfer look up libraries for ice and water clouds will be regenerated, and further tests of the software access of these libraries for cloud optical thickness and effective radius retrievals over various ecosystems will be conducted.

VI. Publications

1. Gatebe, C. K., P. D. Tyson, H. J. Annegarn, S. Piketh and G. Helas, 1999: A seasonal air transport climatology for Kenya. *J. Geophys. Res.*, **104**, 14237–14244.

2. Chou, M. D., K. T. Lee, S. C. Tsay and Q. Fu, 1999: Parameterization for cloud longwave scattering for use in atmospheric models. *J. Climate*, **12**, 159–169.

3. Ou, S. C., K. N. Liou, M. D. King and S. C. Tsay, 1999: Remote sensing of cirrus cloud parameters based on a 0.63-3.7 µm radiance correlation technique applied to AVHRR data. *Geophys. Res. Lett.*, in press.

4. Platnick, S., P. A. Durkee, K. Nielson, J. P. Taylor, S. C. Tsay, M. D. King, R. J. Ferek, P. V. Hobbs and J. W. Rottman, 1999: The role of background cloud microphysics in the radiative formation of ship tracks. *J. Atmos. Sci.*, in press.

5. Durkee, P. A., R. E. Chartier, A. Brown, E. J. Trehubenko, S. D. Rogerson, C. Skupniewicz, K. E. Nielson, S. Platnick and M. D. King, 1999: Composite ship track characteristics. *J. Atmos. Sci.*, in press.

6. Rottman, J. W., S. Platnick, and M. D. King, 1999: Airborne observations of stratus clouds during the southerly surge event of 10-11 June 1994. *Mon. Wea. Rev.*, in press.

7.   King, M. D., Y. J. Kaufman, D. Tanré and T. Nakajima, 1999: Remote sensing of tropospheric aerosols from space: Past, present, and future. *Bull. Amer. Meteor. Soc.*, in press.

8.   Curry, J. A. P. V. Hobbs, M. D. King, D. A. Randall, P. Minnis, G. A. Isaac, J. O. Pinto, T. Uttal, A. Bucholtz, D. G. Cripe, H. Gerber, C. W. Fairall, T. J. Garrett, J. Hudson, J. M. Intrieri, C. Jakob, T. Jensen, P. Lawson, D. Marcotte, L. Nguyen, P. Pilewskie, A. Rangno, D. Rodgers, K. B. Strawbridge, F. P. J. Valero, A. G. Williams, and D. Wylie, 1999: FIRE Arctic Clouds Experiment. *Bull. Amer. Meteor. Soc.*, in press.

9.   King, M. D., and D. D. Herring, 1999: NASA's Earth Observing System: The transition from climate monitoring to climate change prediction. *Sci. Amer.*, in press.

10. Wan, Z., Y. Zhang, X. Ma, M. D. King, J. S. Myers and X. Li, 1999: Vicarious calibration of MODIS Airborne Simulator (MAS) thermal infrared channels. *Remote Sens. Environ.*, in press.

11. Soulen, P. F., S. C. Tsay, M. D. King, G. T. Arnold and J. Y. Li, 1999: Airborne spectral measurements of surface anisotropy during the SCAR-A, Kuwait oil fire, and TARFOX experiments. *J. Geophys. Res.*, in press.

12. Dubovik, O., A. Smirnov, B. N. Holben, M. D. King, Y. J. Kaufman, T. F. Eck and I. Slutsker, 1999: Quality assessments of aerosol optical properties retrieved from AERONET sun and sky-radiance measurements. *J. Geophys. Res.*, in press.

13. Gatebe, C. K., P. D. Tyson, H. J. Annegarn, G. Helas, A. M. Kinyua and S. Piketh, 1999: Characterization of aerosols at a remote high altitude site over equatorial Africa. *J. Geophys. Res.*, in press.

14. Gatebe, C. K., P. D. Tyson, H. J. Annegarn, G. Helas, A. M. Kinyua and S. Piketh, 1999: Inter-Hemispheric transport of aerosols over continental Africa. *Atmos. Environ.*, in press.

15. Wen, G., S. C. Tsay, R. Cahalan and L. Oreopoulos, 1999: Retrieval of aerosol optical thickness over land by using implicit visible and mid-IR relations. *J. Geophys. Res.*, in press.

16. Ji, Q., and S. C. Tsay, 1999: On the dome effect of Eppley pyrgeometers and Eppley pyranometers. *Geophys. Res. Lett.*, in press.

17. Platnick, S., 1999: A superposition technique for deriving photon scattering statistics in plane-parallel cloud atmospheres. *J. Quant. Spectrosc. Radiat. Transfer*, submitted.

18. Platnick, S., 1999: Approximations for horizontal transport in cloud remote sensing problems. *J. Quant. Spectrosc. Radiat. Transfer*, submitted.

19. Baum, B. A., D. P. Kratz, P. Yang, Y. X. Hu, P. F. Soulen, and S. C. Tsay, 1999: Remote sensing of cloud properties using MODIS Airborne Simulator imagery. Part I: Data and models. *J. Geophys. Res.*, submitted.

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21. Ji, Q., S. C. Tsay, Y. J. Kaufman, G. Shaw and W. Cantrell, 1999: CCN supersaturation spectra and CCN size distributions during TARFOX. *J. Geophys. Res.*, submitted.

22. Rolland, P., K. N. Liou, M. D. King, S. C. Tsay and G. M. McFarquhar, 1999: Remote sensing of optical and microphysical properties of cirrus clouds using MODIS channels: Methodology and sensitivity to assumptions. *J. Geophys. Res.*, submitted.

23. Arnold, G. T., S. C. Tsay, M. D. King, J. Y. Li and P. F. Soulen, 1999: Airborne spectral measurements of surface anisotropy for Arctic sea ice and tundra. *Int. J. Remote Sens.*, in preparation.

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10. Nakajima, T., and M. D. King, 1992: Asymptotic theory for optically thick layers: Application to the discrete ordinates method. *Appl. Opt.*, **31**, 7669–7683.

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